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EXPERIMENTAL STUDIES ON
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THE JEJUNAL LOOP TRANSPLANTED INTO
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REFERENCE TO BLOOD CIRCULATION IN
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EXPERIMENTAL STUDIES ON ANTETHORACIC ESOPHAGEAL RECONSTRUCTION BY THE UTILIZATION OF THE JEJUNAL LOOP TRANSPLANTED INTO THE PECTORAL MUSCLE, WITH ESPECIAL REFERENCE TO BLOOD CIRCULATION IN THE LOOP

by

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INTRODUCTION

Various methods of operation for esophageal reconstruction have been devised since the time of BIRCHER⁸⁾, and are now in use. The most important problem with this operation is how to cope with sutural insufficiency in the anastomosed region. Factors held responsible for this sutural insufficiency are many, but the disturbance of blood circulation in the anastomosed region seems to be one of the most important of these factors. Many remedies have been suggested against this circulation disturbance. Prof. AOYAGI conducted a plastic operation for sutural insufficiency resulting from antethoracic subcutaneous esophagogastrostomy at a rather long interval after the primary operation, and clinically observed that rather active vascularization occurred in the transplanted gastric tube as a result. MITSUO TSUKUDA⁴⁹⁾, one of the present author's associates, experimentally investigated the development of new blood vessels from the surrounding tissues into the gastric tube and the jejunal loop transplanted into the antethoracic subcutis. But as the new blood vessels from the subcutis are to be severed in a secondary operation, they cannot be utilized for esophageal reconstruction. This consideration led the present author to attempt the following experiments, namely, histologic examination of vascular development from the pectoral muscle into the jejunal loop transplanted into the same; quantitative determination of circulating blood through the newly-formed vessels; investigation of changes in the motor function of the transplanted jejunal loop; and consideration of the possibility of utilizing the loop for esophageal reconstruction. Further, the author studied the relationship between blood circulation in the transplanted loop and necrosis developing at the tip thereof, and instituted a comparison between antethoracic and intrathoracic esophageal reconstructions.

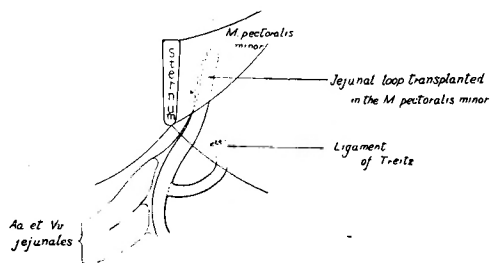
CHAPTER I

Development of New Blood Vessels in the Jejunal Loop Transplanted in the Pectoral Muscle

Section I. Transplantation of the Jejunal Loop into M. Pectoralis minor

Adult mongrel dogs weighing about 10 kg were used as experimental animals. They were given no food for 12-24 hours preceding the operation. Laparotomy was conducted under anesthesia induced by intravenous injections of Nembutal in 0.02 g/kg quantities. One A. et V. jejunalis was cut after the method of WULLSTEIN from the region of the jejunum with adequate distribution of blood vessels which was 20-40 cm off to the anal side from the ligament of Treitz, jejunal loops thus prepared had a closed tip, and ranged in length from 15 to 17 cm. The skin over the outer margin of the left M. pectoralis minor was then incised, and the muscle was cut into two layers, above and below from the outer margin toward the median line. The jejunal loop was located between these two layers. Part of the loop thus covered with the muscle was 7-10 cm long, while the rest was in the thoracic subcutis. Enough care was taken to keep the nutrient vessels from mechanical injuries such as compression, bending and so on (Fig. 1). During the operation,

Fig. 1. Transplantation of the jejunal loop into M. pectoralis minor



local administration of 200,000 units of penicillin was given, and after the operation, subcutaneous injection of 100 cc of Polytamin, and daily intramuscular injections of 600,000 units of penicillin for 5 days. All the experiments to be mentioned later, except the anastomosis experiment with the jejunal loop transplanted into the abdominal muscles, were conducted on the cases which underwent the above-mentioned procedure.

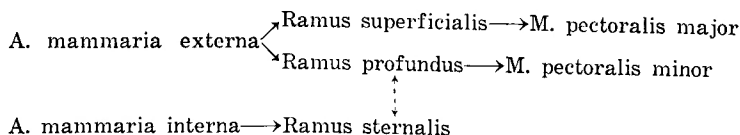
Section II. Histological Findings of The Jejunal Loop Transplanted in M. Pectoralis minor

I. EXPERIMENTAL METHODS

(1) Irrigation with Physiologic Saline Solution

Distribution of the arteries in the pectoral muscles of the dog is shown in Fig. 2. As shown in the figure, it is Ramus profundus, a branch of A. mammaria externa, that chiefly supplies blood to M. pectoralis minor. And there exists an anastomosis between this and Ramus sternalis, a branch of A. mammaria interna.

Fig. 2. Distribution of the arteries in the pectoral muscles of the dog



Under intravenous anesthesia by Nembutal, the experimental dog was bled to death by cutting open its abdominal aorta. Immediately after death the mouth of the aorta, left and right Aa. carot. communes, and Aa. brachiales were deligated, and at the same time V. cava cranialis and V. cava caudalis were incised. The

antethoracic irrigation system was then constructed by inserting a vinyl tube from the incised opening of the abdominal aorta into the thoracic aorta. Physiologic saline solution heated at about 40°C was used for irrigation, which was done under a pressure of about 130 cm H₂O. Irrigation was continued for about one hour, until the skin and the muscles became whitish. The amount of physiologic saline solution used was about 15 l.

(2) Injection of India Ink

An India ink solution was prepared by rubbing a stick of Kokaboku (an ink stick of superior quality) on an inkstone made of superior material, and passed through a filter paper. Gelatin was added to the ink solution in 7% volume. This solution was heated at about 40°C. After irrigating with physiologic saline solution, the transplanted jejunal loop was doubly deligated together with the blood vessels just above the point where it goes out of the peritoneum, and then cut so that the India ink solution might flow into the jejunal loop only through the newly-formed blood vessels. Two hundred~300 cc of the ink solution was injected through the vinyl tube inserted into the thoracic aorta at a rate of 100 cc per 5 minutes until the antethoracic region was sufficiently stained with the ink.

(3) Preparation of Specimens

On termination of the India ink injection, the whole body of the dog was soaked in a vat containing a 10% formalin solution, and left there for a week. This was done to prevent the possible outflow of the ink at the time of excision of the transplanted jejunal loop with the surrounding tissues.

The jejunal loop covered with the tissues was cut in round slices. These slices were embedded in celloidin after being again fixed in formalin, and afterward stained with hematoxylin-eosin.

II. HISTOLOGICAL FINDINGS

(1) Findings One Week after Transplantation (Fig. 3)

The arteries and veins in the pectoral muscle around the jejunal loop were filled with the injected India ink. Cell infiltration consisting chiefly of neutrophils, and granulation in which proliferation of monocytes predominated were both present. The surface of the serous membrane was hardly recognizable, and the formation of a granulation layer was seen to have taken place between the striated muscles and the longitudinal muscles of the jejunum. In this granulation layer were noted newly-formed capillaries which contained particles of India ink. Proliferation of the interstitial tissue was spreading from this granulation layer toward the longitudinal muscles. It was accompanied with cell infiltration. Proliferation of the same sort was also seen in the circular muscle, the submucous layer, and the connective tissue under the proper muscle layer. Blood vessels not only in this proliferative granulation tissue, but in the mucous membrane as well, had suffered inflow of particles of India ink. Vacuolar degeneration was noted in the muscle layer of the jejunum. The mucous membrane, too, showed mild degenerative changes.

(2) Findings Three Weeks after Transplantation (Fig. 4)

Inflammatory changes in the striated muscles adjacent to the loop had become somewhat milder, and the granulation layer showed a tendency to fibroplasia. In some portions of the muscle layer, slight proliferation of the interstitial tissue was noted. Inflammatory changes in the submucous and the proper layers had subsided. Granulation in these layers was also in a state of mild fibrosis. The mucous membrane presented a picture of atrophy, and goblet cells in particular had fallen into marked atrophy. The peripheral parts of the mucous membrane showed signs of bionecrosis. Particles of India ink were found in the blood vessels of the muscular layer, and in the mucous membrane.

(3) Findings Six Weeks after Transplantation (Fig. 5)

Fibroplasia was further advanced in the granulation layer adjoining the transplanted loop. This layer had become adherent to the longitudinal muscles, and had well-developed new capillaries. Mild infiltration of monocytes and eosinophils was noted. In some portions of the muscular layer of the jejunum normal arrangement of muscle fibers had been disturbed owing to the proliferated granulation tissues, and in general, this layer had lost, to some extent, its eosinophilic property. Inflammatory changes were still present in the submucous layer, but they presented a picture of chronic inflammation in which lymphocytes predominated. The basal part of the mucous membrane remained nearly normal, while the peripheral part had partially fallen into bionecrosis, and partially showed epithelial regeneration.

Throughout these different periods the pathologic changes seemed to be somewhat more marked in the top part of the loop than in its root.

Section III. Quantitative Measurement of Newly-Formed Blood Vessels Going from the Surrounding Tissues into The Jejunal Loop Transplanted in *M. Pectoralis minor*.

Quantitative measurement of newly-formed blood vessels in the transplanted loop is essential for choosing an opportune period for the secondary operation, and so, the following experiments were carried out.

I. EXPERIMENTAL METHODS

(1) Suspension of P^{32} -Labeled Erythrocytes

Forty cc of blood was taken from the femoral artery of the experimental dog into a syringe already containing 3 cc of a 10% sodium citrate solution, and immediately spun down for 10 minutes at 2000 revolutions per minute so as to separate plasma from blood cells. A sodium citrate solution equal in volume to the separated plasma was given to the separated blood cells. This suspension was again centrifuged. The centrifugation was repeated three times in all to wash the blood cells. These cells were then suspended in a physiologic saline solution with P^{32} added. After this suspension had been mixed well, it was kept at 37°C for 2 hours, during which time it was slightly shaken and mixed every 10-20 minutes. The added P^{32} was in the form of Na_3PO_4 , and its amount was 800-1200 μ c. Washing of the blood cells by the above procedure was again repeated four times.

Results of a check examination of this method of preparing a suspension of

P^{32} -labeled erythrocytes has already been published by MASANORI MAJIMA³²⁾, one of the present author's associates.

(2) Measurement of Circulating Blood in The Jejunal Loop Immediately after Being Prepared for Transplantation

Under intravenous anesthesia by Nembutal the jejunal loop was made after the method of WULLSTEIN. The number of Aa. et Vv. jejunaes severed, differed in three ways with cases; that is, it was one, two and three.

Ten minutes after production of the jejunal loop 40 cc of the P^{32} -labeled erythrocyte suspension was injected into the femoral vein. With loops with three Aa. et Vv. jejunaes cut radioactivity was measured at intervals of 4 cm all the way from root to tip with a Geiger-Mueller counter manufactured by the Shimazu Company. With the other loops, measurement was done at the tip portion. The normal control portion of jejuna were also measured at three different places. In all cases the side opposite to mesenterial attachment was chosen as the site of measurement.

(3) Measurement of Circulating Blood Volume in The Jejunal Loop through Newly-Formed Blood Vessels

(i) Radioactivity Measurement on Living Dog

Fig. 6. Site of measurement of circulating blood volume in the intramuscularly transplanted jejunal loop by way of newly-formed blood vessels.

Measurement on living dog.

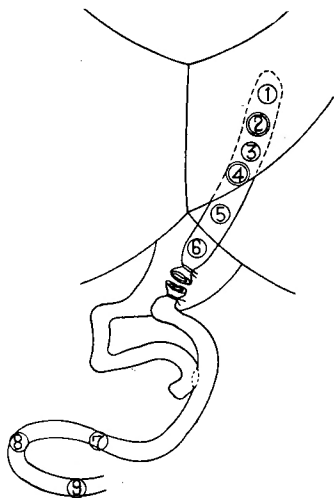
②, ④ : Portion where the skin and muscle was excised in a circle 1.2 cm across.

Measurement by dry incineration.

①~④ : Portion transplanted intramuscularly.

⑤~⑥ : Portion transplanted subcutaneously.

⑦~⑨ : Normal jejunum (control).



Under intravenous anesthesia by Nembutal, the skin and muscle over the transplanted jejunal loop was excised in a circle 1.2 cm across. The loop was thus exposed, care being taken not to damage it. This exposure was made at two different places, namely, at the tip and the root of the loop. Next, laparotomy was conducted, and the loop was deligated, and severed together with Aa. et Vv. jejunaes just above the point where it went out of the peritoneum. Its original blood routes being thus completely destroyed, it could not be reached by the blood stream except through the newly-formed blood vessels (Fig. 6). Ten minutes after the above procedure 40 cc of the P^{32} -labeled erythrocyte suspension was injected into V. femoralis. Further, 15 minutes later radioactivity was measured with a Geiger-Mueller counter at the two exposed places of the loop. Measurement of radioactivity was also done on normal control jejuna.

(ii) Radioactivity Measurement by Dry Incineration

After the above measurement was finished, 40 mg of succinylcholine chloride was injected intravenously into the dog in order to minimize the effects of intestinal contraction at the time of death. The dog was killed by cutting open both sides of the thorax, and both the transplanted jejunal loop and normal portion of jejunum were taken out. Electrocautery was employed in decorticating the loop from the mesentery to avoid the outflow of the blood as much as possible. A piece of tissue 1 cm in length was cut off from the transplanted loop and the control jejunum, weighed, and put into an ointment can. This can was gradually heated in an electric furnace, and kept at about 700°C for an hour. The ash thus produced was measured by a Geiger-Mueller counter for radioactivity. By the way, our preliminary experiments on this subject, results of which M. TSUKUDA⁴⁹⁾ reported, had clearly established that this method of dry incineration permitted no measurement errors due to evaporation of P³².

II. EXPERIMENTAL RESULTS

(1) Volume of Circulating Blood in The Jejunal Loop Immediately after Being Prepared

Radioactivity at the tip portion of the loop with one severed A. et V. jejunalis was 63% of the mean radioactivity of the control jejuna, while that of the loop with two severed Aa. et Vv. jejunaes was 47%. Values of radioactivity at different places of the loop with three severed Aa. et Vv. jejunaes are shown in Table I.

(2) Amount of Newly-Formed Blood Vessels

(i) Measurement on Living Dog (Table II)

The volume of circulating blood in the transplanted jejunal loop through newly-formed blood vessels was measured at the tip and the middle part of the loop

Table I. The volume of circulating blood in the jejunal loop immediately after being prepared (using P³²-labeled erythrocytes).

Site* of meas- urement	No. 1		No. 2		No. 3		No. 4	
	measurement value (cpm)	%	measurement value (cpm)	%	measurement value (cpm)	%	measurement value (cpm)	%
1	277	80.2	526	111.1	264	82.4	239	93.2
2	235	68.1	456	96.6	274	85.3	242	94.4
3	180	52.1	386	81.8	204	63.7	211	82.3
4	326	94.5	270	57.1	270	84.2	208	81.3
5	220	63.7	294	62.4	233	72.2	161	62.8
6	190	55.0	154	32.6	234	73.0	79	30.8
7	152	44.2	204	43.2	201	62.3	92	35.1
8	161	46.7			167	52.1		
9	81	23.5			139	43.4		
10					79	24.2		
average of control	345	100	473	100	323	100	256	100

* v. Fig. 27.

Table II. The volume of circulating blood in the intramuscularly transplanted jejunal loop by way of newly-formed blood vessels.(1) Measurement on living dog (using P^{32} -labeled erythrocytes)

A : value obtained (cpm)

nc : natural counts (cpm)

After transplantation		10 days		1 month		2 months		3 months	
Site of measurement		A - nc	%	A - nc	%	A - nc	%	A - nc	%
intramuscularly transplanted jejunal loop	2	142	27	172	70	253	79	386	74
	4	121	23	176	72	258	80	371	71
normal portion of jejunum (control)	7	487	100	245	100	306	100	514	100
	8	539		274		322		524	
	9	549		216		341		531	

respectively 10 days, 1, 2 and 3 months after transplantation. The values obtained at the tip were respectively 27%, 70%, 79% and 74% of the normal, while those at the middle part were respectively 23%, 72%, 80% and 71%. That is, the circulating blood increased in volume in all cases till the 2nd month after transplantation. The values obtained three months later, however, were somewhat smaller than those two months later.

(ii) Measurement by Dry Incineration (Table III)

The values obtained by this measurement on the loop 10 days, 1, 2 and 3 months after transplantation were respectively 35.5%, 74.0%, 83.5% and 80.2% of the normal. That is, the amount of P^{32} in the loop tended to increase with length of interval after transplantation. The fact that the values obtained two and three months later were very similar to each other indicates that the formation of new blood vessels had been nearly completed in the 2nd month after operation.

Table III. The volume of circulating blood in the intramuscularly transplanted jejunal loop by way of newly-formed blood vessels.(2) Measurement by dry incineration (using P^{32} -labeled erythrocytes)

A : value obtained (cpm)

nc : natural counts (cpm)

W : weight of pieces of tissue (g)

after transplantation		10 days		1 month		2 months		3 months	
Site of measurement		A - nc/W	%	A - nc/W	%	A - nc/W	%	A - nc/W	%
intramuscularly transplanted jejunal loop	1	77/1.02	23	312/1.22	75	384/1.02	89	1667/1.72	86
	2	101/1.30	24	293/1.30	66	409/1.34	72	1175/1.48	70
	3	142/1.42	31	307/1.22	74	414/1.24	79	1166/1.26	82
	4	114/1.22	29	282/1.20	69	428/1.22	83	1566/1.77	79
	5	213/1.20	55	319/1.20	78	473/1.30	86	1717/1.82	84
	6	221/1.34	51	501/1.32	82	486/1.25	92		
average			35.5		74.0		83.5		80.2
normal portion of jejunum (control)	7	423/1.30	100	387/1.10	100	551/1.23	100	1606/1.62	100
	8	409/1.24		411/1.22		581/1.43		1542/1.52	
	9	441/1.40		394/1.18		457/1.10		2338/1.93	

On an average the values obtained by measurement on living dog are rather lower than those obtained by the method of incineration. This may be due, as M. TSUKUDA has pointed out, to the effects of post-mortem changes, but it is also probable that partial destruction of the newly-formed blood vessels through perforation of the muscles in the case of measurement on living dog is at least partly responsible for this.

Section IV. Motor Function of The Jejunal Loop Transplanted into M. Pectoralis minor

I. EXPERIMENTAL METHODS

A small hole was made at the tip of the jejunal loop transplanted in M. pectoralis minor, and through this hole was inserted about 5 cm deep a Nélaton's catheter No. 15, to the tip of which a balloon 3 cm in length was attached. This catheter being connected with a water manometer, a small amount of air was pumped into the balloon under a pressure of 4 cm H₂O, and the curves of intrajejunal tension were drawn on soot paper. To ascertain the effects of breathing on the tension, a manchette wound around the thorax was connected with a tambour, and respiration curves were recorded simultaneously. With regard to the normal control dog, Witzel's jejunal fistula was made, and through this fistula a balloon was likewise inserted. The curves of intrajejunal tension were drawn 10 days after production of the fistula, lest the after-effects of the surgical procedure should interfere with experimental results. All these experiments were conducted under intravenous anesthesia by Nembutal (Fig. 7).

II. EXPERIMENTAL RESULTS

Internal tension curves were examined for frequency and amplitude of small waves, and tonus waves. Frequency of small waves per minute was counted at the beginning and end of the curve, and also in the parts of the curve where the amplitude was largest and smallest. These counts were averaged. As to the amplitude, its largest and smallest swings were measured, and as to the tonus wave, frequency in its appearance per 10 minutes was counted¹¹⁾.

In controls jejunal movement regularly occurred spaced by a 10 or 10-odd minutes long rest period, but the transplanted loop hardly showed any spontaneous movement. Its movement, however, was provokable by slight stimulation with the balloon. With controls, no appreciable difference was discernible between such provoked movements and spontaneous ones. Measurement values refer to provoked movements (Fig. 8-14), and are given in Table IV.

Frequency of small waves one and two months after transplantation was only

Fig. 7. Apparatus for drawing internal tension curve in jejunum.

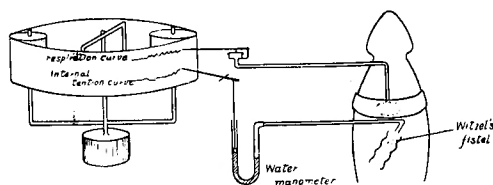


Table IV. Internal tension curves of the jejunal loop transplanted into *M. pectoralis minor*.

		Control	15 days after transplantation	1 month after transplantation	2 months after transplantation
Small Waves	frequency per minute	9.6	14.1	11.2	11.1
	amplitude min.—max.	0.6mm-7.4mm	0.3mm-1.4mm	0.4mm-2.1mm	0.3mm-3.3mm
Tonus waves Frequency per 10 minutes		6—10	—	—	—
Type of waves (LAWSON & TEMPELTON)		Type I & Type III	Type I	Type I	Type I

a little higher than that of controls, but 15 days later it had been rather markedly increased. The maximum amplitude 15 days after transplantation was greatly reduced, namely, to about one-fifth of that of controls. It showed a slight improvement one month later, and two months later was restored to almost one-half of the normal. As for the tonus wave, it was hardly shown by the transplanted loop.

Next, the curves were analysed according to LAWSON and TEMPELTON's classification¹³). LAWSON and TEMPELTON classed frequent, and tiny non-propulsive contraction waves under Type I, and under Type II, strong propulsive contraction waves, or peristalsis. Type III was a combination of the above two types (Fig. 15). Controls showed waves of Type I, and Type III, but in the transplanted loop waves of Type I alone were noted.

It is clear from the above findings that jejunal movements are reduced by transplantation to a considerable extent. Some improvement sets in one or two months after transplantation, it is true, but after all, the postoperative motor function of the jejunum shows a remarkable decline, compared with the preoperative.

Section V. A Few Attempts to Increase Circulating Blood Volume

I. USE OF ASBESTOS POWDER

By sprinkling of asbestos powder I tried to cause a strong and extensive adhesion of the transplanted jejunal loop to the neighboring tissues, and thereby accelerate the formation of new blood vessels.

(1) Experimental Methods

After the method described in Section I, the transplantation of the jejunal loop

Fig. 15. Types of internal tension curve in the jejunal loop transplanted intramuscularly (LAWSON & TEMPELTON).

into *M. pectoralis minor* was carried out, but this time 0.1 g of asbestos powder was sprinkled on the tissues adjacent to the loop. As the gross grains of this powder would rather obstruct the formation of new blood vessels, the powder was passed through a 60-mesh screen, and only these fine grains were used.

Quantitative determination of circulating blood in the newly-formed blood vessels was done after the manner described in Section III 15 days, 1 and 2 months after transplantation.

(2) Experimental Results (Tables V and VI, Fig. 16)

Fig. 16. The volume of circulating blood in the intramuscularly transplanted jejunal loop by way of newly-formed blood vessels.

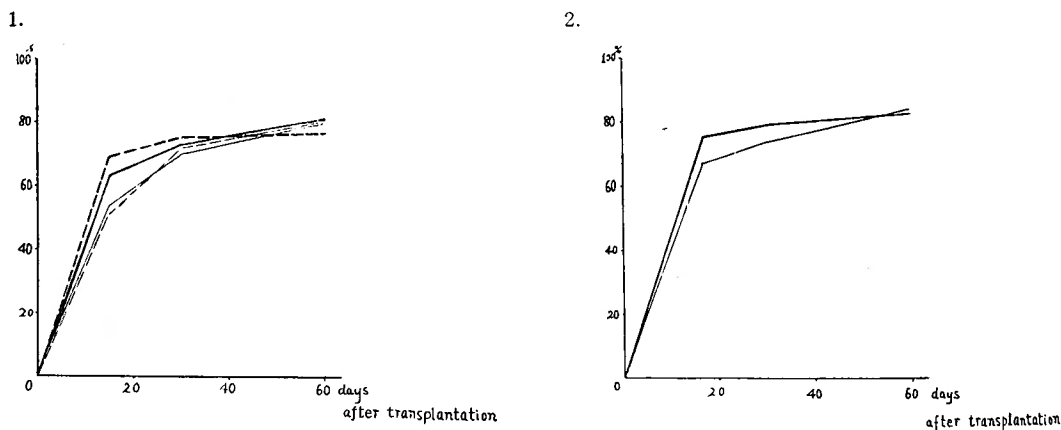
Accelerating the formation of new blood vessels through sprinkling of asbestos powder.

1. Measurement on living dog.

- | | | |
|-----------------------|---|---|
| — peripheral portion | } | simple intramuscular transplantation |
| - - - central portion | | |
| — peripheral portion | } | intramuscular transplantation with sprinkling of asbestos |
| - - - central portion | | |

2. Measurement by dry incineration.

- | |
|---|
| — simple intramuscular transplantation |
| — intramuscular transplantation with sprinkling of asbestos |



Fifteen days after transplantation the volume of circulating blood through the newly-formed blood vessels was about 10% greater in cases treated with asbestos sprinkling than in those non-treated, and one month later about 5% greater. But there was no marked difference on this point, the two months later.

(3) Histological Findings

Fifteen days after transplantation the striated muscle fibers around the jejunal loop were noted to have fallen into rather intense degeneration, and connective tissues had actively proliferated between the striated muscles and the jejunal muscular layer. Many monocytes had infiltrated, and foreign-body giant cells were also found in large numbers around the grains of asbestos powder. The mucous membrane presented a picture of atrophy (Fig. 17-18).

Histological findings one and two months later were nearly the same. Degeneration was further advanced in the striated muscles, while inflammation had abated,

Table V. The volume of circulating blood in the intramuscularly transplanted jejunal loop by way of newly-formed blood vessels.
Accelerating the formation of new blood vessels through sprinkling of asbestos powder.

Site of measurement		15 days after transplantation				1 month after transplantation				2 months after transplantation			
		simple intra-muscular transplan-tation		intramuscu-lar trans-plantation with sprin-kling of asbestos		simple intra-muscular transplan-tation		intramuscu-lar trans-plantation with sprin-kling of asbestos		simple intra-muscular transplan-tation		intramuscular transplan-tation with sprinkling of asbestos	
		L.D.	D. I.	L.D.	D. I.	L.D.	D. I.	L.D.	D. I.	L.D.	D. I.	L.D.	D. I.
Jejunal loop transplanted intramus-cularly	1		47%		64%		75%		75%		89%		88%
	2	54%	58	64%	72	70%	66	73%	73	79%	72	81%	83
	3		75		80		74		81		79		75
	4	52	59	69	77	72	69	75	78	80	83	77	80
	5		81		78		78		83		86		86
	6		83		84		82		85		92		87
	average		67.2		75.8		74.0		79.2		83.5		83.2
normal portion of jejunum (control)		100	100	100	100	100	100	100	100	100	100	100	100

L. D. : measurement on the living dogs

D. I. : measurement by dry incineration

Table VI. a.

site of measurement	value of measurement (cpm)	percentage
(1)	777	75.4%
(2)	816	79.1%
normal portion of jejunum (control)	1030	100 %

Table VI. b.

	value of measurement (cpm)	percentage
before treatment	1052	100%
after deligation of (a) and excision of (b)	1055	100.3%

and the granulation tissues between the muscles and the loop had somewhat diminished in size, and now adhered well to the muscular layer, which presented a nearly normal appearance. The basal part of the mucous membrane remained unaffected, though its periphery suffered bionecrosis. Bionecrosis of the mucous membrane was of milder nature two months later than it had been one month before, and some signs of regeneration were detected.

II. POSSIBILITY OF INCREASING BLOOD SUPPLY TO THE TIP OF THE ISOLATED JEJUNAL LOOP THROUGH PARTIAL EXCISION OF A JEJUNAL SEGMENT WHICH IS NOURISHED BY THE SAME BLOOD VESSELS AS THE TIP.

KATSURA et al. stated that blood supply to an isolated jejunal segment with its vascular supply was maintained in a relatively good condition by partial excision of its segment²³⁾²⁴⁾. The present author reduced the size of vascular bed by excision,

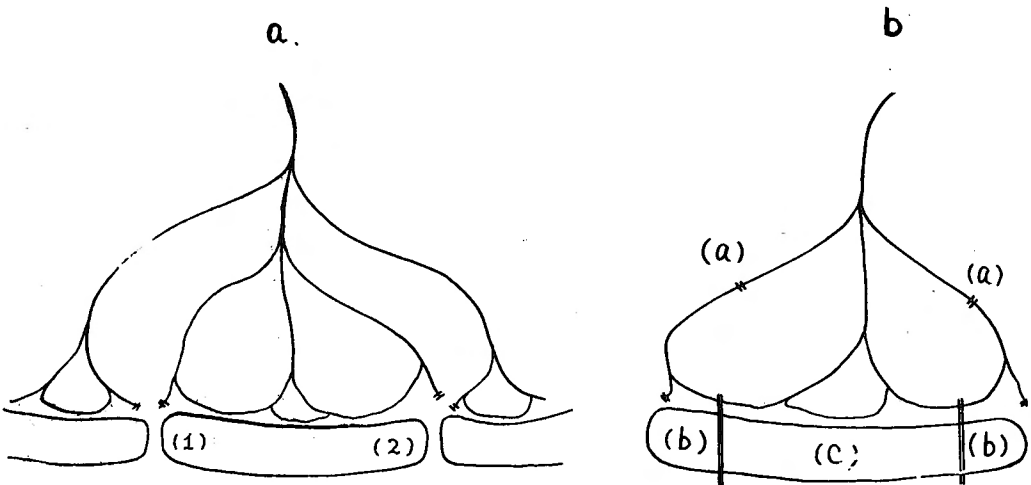


Fig. 19. Changes of blood stream in the jejunal portion left unexcised by means of diminution of vascular bed.
Case in the jejunum with nearly normal volume of circulating blood.

and investigated quantitatively the possibility, by this method, of increasing blood supply to the tissue left unexcised (a jejunal segment).

(1) Experimental Methods

(i) As shown in Fig. 19, a, the connection between the left and right sides of the jejunum was completely broken. Aa. and Vv. jejunales to this jejunal segment were kept as they were. After an injection of the P^{32} -labeled erythrocyte suspension was done, radioactivity was measured at the sites marked (1) and (2).

(ii) An isolated jejunal segment was prepared in the same way as the above. Radioactivity was measured at the site marked (c). Next, as shown in Fig. 19, b, deligation was done at the site marked (a). The portion marked (b) was excised. Again radioactivity was measured at the site marked (c).

(iii) A jejunal loop with a closed tip was produced by deligating the places (A) and (B) (Fig. 20). Radioactivity was measured at the sites 1, 2, 3 and 4. Next, deligation was done at the sites (C) and (D), and the portion (E) was excised. Again radioactivity was measured at the sites 1, 2, 3 and 4.

(2) Experimental Results

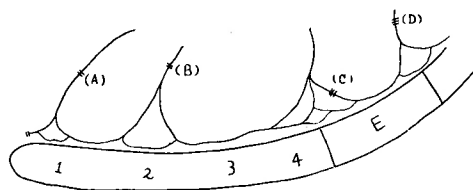
Results are shown in Tables VI and VII. When the volume of circulating blood

Table VII.

site of measurement	after deligation of (A) and (B) (a)	after deligation of (C) and (D) and excision of (E) (b)	$\frac{b-a}{a} \times 100\%$
1	312	420	+ 37.8%
2	686	779	+ 14.0%
3	771	931	+ 20.9%
4	814	881	+ 8.2%
ave rage of control (normal jejunal portion)	1001	998	(- 0.3%)

in the segment was not so much lessened, namely, 75-80% of the normal, the diminution of vascular bed by excision of (b) did not particularly increase the volume of circulating blood in the unexcised part. But at the tip of the loop described in (iii) where blood volume showed a marked decrease compared with the normal, the diminution of the vascular bed by excision of (E) brought about remarkable, namely, 37.8% increase of circulating blood.

Fig. 20. Changes of blood stream by means of diminution of the vascular bed in the jejunal portion left unexcised. Case in the jejunum with the reduced blood stream.



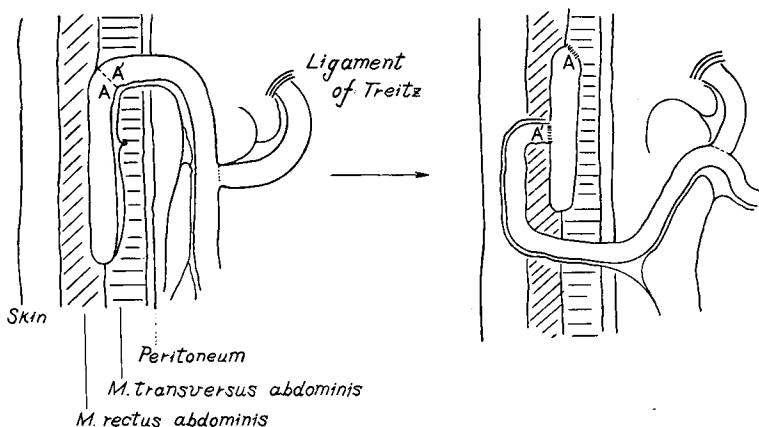
Section VI. Anastomosis Experiments with The Isolated Jejunal Segment Transplanted into Muscles

From the above experiments it was noted that the volume of circulating blood through the newly-formed blood vessels coming into the jejunal loop from the surrounding muscles amounts to nearly 80% of the normal two months after transplantation, while the experiments of M. MAJIMA³⁷⁾, one of the present author's associates, and the present author's own experiments which will be described later in Section III, Chapter II, have shown that about 60-80% of the normal blood volume is just enough to keep the jejunum from falling into necrosis. In view of these facts it was considered that a blockade of normal vascular supply would not cause necrosis in the jejunal loop transplanted into muscles. The following experiments were conducted to prove this supposition.

The jejunal loop, prepared in the same way as was described in Section I, was transplanted between M. rectus abdominis and M. transversus abdominis. Sprinkling of asbestos powder was resorted to. Two months after transplantation the loop was severed together with Aa. et Vv. jejunales at the site where it entered M. transversus abdominis, and its severed end on the distal side was closed with suture. Next, a portion of M. rectus abdominis was freed from its ventral attachment along its longer axis as far as middle part of the transplanted loop, and then an end-to-side anastomosis was done between this middle part of the transplanted segment and the severed end on the central side of the loop (Fig. 21). One hundred cc of Polytamin was subcutaneously injected immediately after this procedure, and thereafter for three consecutive days. Intramuscular injection of penicillin in 6×10^5 units quantities was also daily done for five postoperative days. The experimental animal was killed two months later, and dissected. The anastomosed part showed a complete healing, and the mucous membrane of the segment was macroscopically normal. As for the serous membrane, it was found adhering firmly to the neighboring muscles (Fig. 22 and 23).

Histological Findings (Fig. 24 and 25): The tip of the mucous membrane of the loop had fallen into bionecrosis, and its chromatic property was damaged. The basal part, however, remained normal, and showed little atrophy. The muscular

Fig. 21. Experiment of anastomosis using isolated jejunal segment transplanted into abdominal muscles with blood supply by newly-formed blood vessels alone.



layer, was also nearly normal. There was not much granulation tissue between the segment and the striated muscles (abdominal muscles), and excellent healing as planned was noted. Inflammation was hardly noticeable. Fat was present in the striated muscles around the segment, and also interbedded between the muscles. The nuclei of muscle cells had become pyknotic, and showed marked atrophy. In the anastomosed part the mucous membrane and the muscular layer showed excellent healing as planned. Chronic inflammation was present only around sutural threads, and infiltration of plasma cells, lymphocytes, monocytes and neutrophils was noted.

Another attempt was made to anastomose the jejunal loop transplanted in *M. pectoralis minor* with cervical esophagus. This operation was to be conducted in two steps. As a first step, one more *A. et V. jejunalis* was severed, and *M. pectoralis minor* was freed from the sternum along its marginal attachment to the latter. The jejunal loop was then moved upward together with this muscle until the tip of the loop came 1-2 fingerbreadths up from the upper end of the sternum. Unfortunately, this case contracted a subcutaneous infection, and developed into an abscess. As a result the lips of the operation wound were opened again. But the loop itself was free from necrosis, and in a good condition.

Chapter II

Comparison of Antethoracic Jejunal Transplantation with The Intrathoracic Transplantation

According to our clinical experience sutural insufficiency is somewhat more apt to occur in the case of antethoracic transplantation than in that of the intrathoracic. The following experiments were conducted to see if this fact might be explained by the state of blood circulation in the jejunal loop.

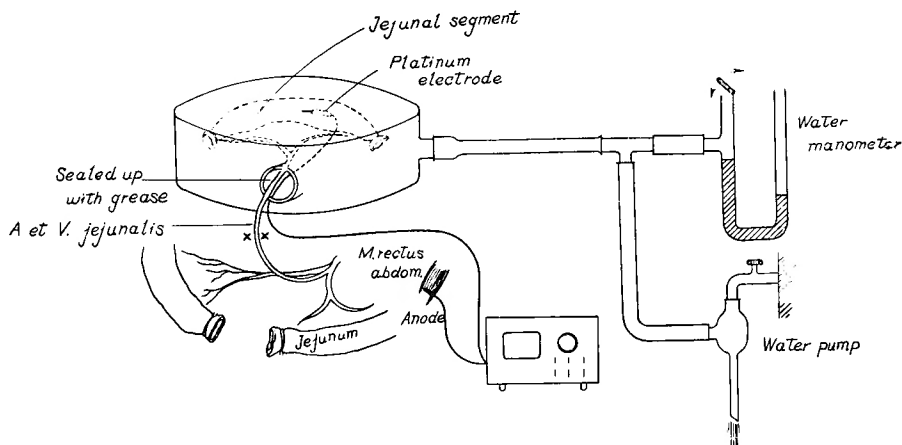
Section I. Effects of Negative Pressure on Blood Circulation in The Transplanted Jejunal Segment

I. EXPERIMENTAL METHODS

(1) Measurement with An Oxygraph¹⁶⁾⁴⁸⁾

An isolated jejunal segment with vascular supply was manufactured. A platinum electrode was inserted under the serous membrane, and fixed there. The region around the electrode was insulated from air with liquid paraffin. This jejunal segment was put into a glass container, as shown in Fig. 26. One opening of the container was sealed up with grease, and the other opening was connected with a water manometer and a water pump. By opening and shutting a valve attached to the manometer, a negative pressure of 7-8 cm H₂O was rhythmically produced in the container twenty times per minute. Oxygen tension in the subserous tissue was measured by an oxygraph under the above-mentioned negative pressure as well as under normal pressure. This measurement was done after oxygen tension had become stable under normal pressure.

Fig. 26.



An oxygraph of type II model made by the Shimazu Company was used with alternating voltage (3 cpm). The platinum electrode was of open-tip type, and 0.3 mm in diameter. An Ag-AgCl electrode was used for anode. Positive and negative voltages were respectively fixed at +0.7v and -0.5v.

(2) Measurement with The P³²-Labeled Erythrocyte Suspension

The P³²-labeled erythrocyte suspension was injected in the way described in Section III, Chapter I, and the nutrient blood vessels were measured for radioactivity with a Geiger-Mueller counter.

II. EXPERIMENTAL RESULTS

As shown in Tables VIII and IX, these measurements revealed that the blood circulation of the isolated jejunal segment was nearly the same under negative pressure as under normal pressure.

Section II. Difference in Temperature between The Antethoracically and The Intrathoracically Transplanted Jejunal Loops

Table VIII. Effects of negative pressure on blood circulation in the transplanted jejunal segment.
1. Oxygen tension in the subserous tissue of jejunal segment.

	Case 1			Case 2		
	I	II	average	I	II	average
normal pressure	30.64 μ A	22.52 μ A	26.58 μ A	11.17 μ A	9.23 μ A	10.20 μ A
negative* pressure	30.69	22.49	26.59	12.09	8.81	10.45

* A negative pressure of 7-8 cm H₂O was rhythmically produced in the container twenty times per minute.

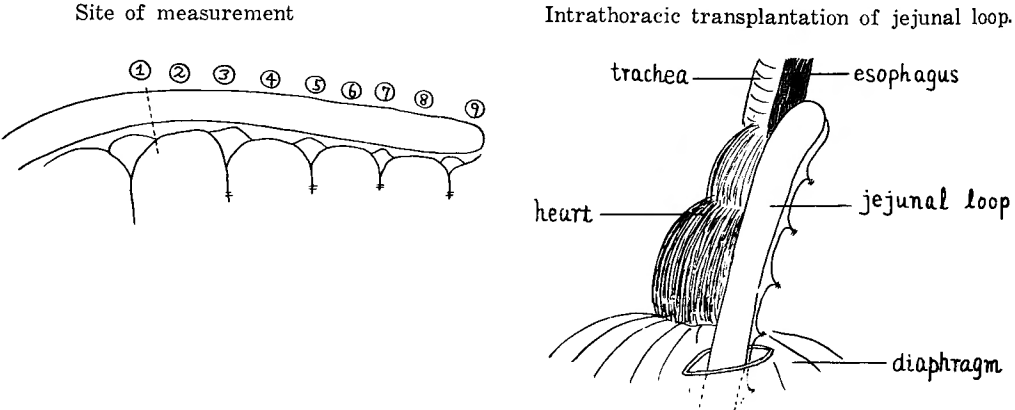
Table IX. Effects of negative pressure on blood circulation in the transplanted jejunal segment.
2. Radioactivity in the nutrient blood vessels (using P³²-labeled erythrocytes)

	Case 1				Case 2			
	cpm	cpm	cpm	average	cpm	cpm	cpm	average
normal pressure	1402	1601	1427	1477 (100%)	832	933	904	889 (100%)
negative pressure	1423	1448	1429	1433 (97.1%)	924	883	941	916 (103.2%)

I. EXPERIMENTAL METHODS

Two jejunal loops were made in each dog after the method of WULLSTEIN. On a first dog, one A. et V. jejunalis was deligated, while on a second dog, three sets of A. et V. jejunalis were deligated, in order to cause necrosis at the tips of the loops. At the tip and the middle part of each loop the thermo-couples of a micro-pyrometer were inserted and fixed there. The two loops were then transplanted respectively into the antethoracic subcutis and the thoracic cavity. In intrathoracic transplantation an aperture about 5 cm long was made in the anterior middle part of the diaphragm, and the loop was pulled up through this aperture, and fixed to the thoracic pleura (Fig. 27). Care was exercised not to damage the loop by bending, traction, and compression of the nutrient blood vessels. Temperature was taken every 30 minutes after transplantation. Room temperature was also recorded

Fig. 27. Comparison between antethoracic and intrathoracic transplantation on the point of necrosis development.



simultaneously. Measurement of temperature was done with an EKO micropyrometer, and copper-constantan thermocouples were inserted into the jejunum.

II. EXPERIMENTAL RESULTS

In one case one A. et V. jejunalis was subjected to deligation, and the loops about 15 cm long were prepared. Results obtained from this case are presented in Table X.

Table X. Temperature of transplanted jejunal loops
Case 1.

after transplantation		30min.	60min.	90min.	120min.	150min.	180min.
antethoracic	peripheral part	29.4°C	30.4	30.9	30.8	31.6	32.1
transplantation	central part	26.3	27.7	28.6	28.8	29.4	29.5
intrathoracic	peripheral part	29.6	30.7	31.6	31.8	32.1	32.5
transplantation	central part	29.3	30.5	31.1	31.6	32.0	32.0
room temperature		12.2	11.9	11.4	10.7	10.1	9.7

Table XI. Case 2.

after transplantation		30min.	60min.	90min.	120min.
antethoracic	peripheral part (necrosis)	25.0°C	24.9	24.8	24.5
transplant.	central part	27.4	26.1	26.1	25.7
intrathoracic	peripheral part (necrosis)	28.9	28.2	27.5	27.0
transplant.	central part	30.5	28.4	28.4	27.8
room temperature		16.7	17.0	17.0	15.0

In a second case three sets of Aa. et Vv. jejunaes were deligated, and the length of the loops was about 30 cm. In this second case the tips of the both loops were later affected with necrosis. Its experimental results are presented in Table XI.

The intrathoracically transplanted loops showed a somewhat higher temperature than the antethoracically transplanted. But the temperature difference between the two at the tip where necrosis developed later were nearly the same as that at the basal part.

Section III. Comparison between Antethoracic and Intrathoracic Transplantation on The Point of Necrosis Development

I. EXPERIMENTAL METHODS

Jejunal loops were made as described in the preceding section. This time the loops were all made about 30 cm long, and three sets of Aa. et Vv. jejunaes were deligated. The loops were marked by fine silk thread at regular intervals. Forty cc of the P³²-labeled erythrocyte suspension was injected into V. femoralis, and 15

minutes later radioactivity was measured at the marked sites. Then the loops were transplanted either into the antethoracic subcutis, or into the thoracic cavity. In due time, the animals were sacrificed, and the necrosed parts were examined (Fig. 27).

II. EXPERIMENTAL RESULTS

Results obtained are given in Table XII. The necrosed sites are marked by

Table XII. The relation between circulating blood volume in the jejunal loop immediately after being prepared for antethoracic and intrathoracic transplantation and point of necrosis development after transplantation.

Site of measurement	antethoracic transplantation				intrathoracic transplantation			
	No. 1		No. 2		No. 3		No. 4	
	measurement value	%	measurement value	%	measurement value	%	measurement value	%
1	277	80.2	526	111.1	264	82.4	239	93.2
2	235	68.1	456	96.6	274	85.3	242	94.4
3	180	52.1	386	81.8	204	63.7	211	82.3
4	326	94.5	270	57.1	270	84.2	208	81.3
5	220	63.7	294	62.4	233	72.2	161	62.8
6	190	55.0	(154)	(32.6)	234	73.0	(79)	(30.8)
7	(152)	(44.2)	(204)	(43.2)	201	62.3	(92)	(35.1)
8	(161)	(46.7)			(167)	(52.1)		
9	(81)	(23.5)			(139)	(43.4)		
10					(79)	(24.2)		
average of control	345	100	473	100	323	100	256	100

(), and radioactivities at all these sites were below 55% of the normal. Radioactivity at the unaffected part adjoining these necrosed sites was more than 55% in all cases, and nearly always exceeded 60%. Accordingly, 55% of the normal may be regarded as the limit of resistance to necrosis. No appreciable difference was detected in results of radioactivity measurement between the antethoracically and the intrathoracically transplanted jejunal loops.

DISCUSSION

Sutural insufficiency in the anastomosed region forms one of the most knotty problems in esophageal reconstruction. The following factors may be mentioned as responsible for sutural insufficiency in esophago-gastrostomy and esophago-enterostomy. (1) Lack of the serous membrane in the esophagus. (2) Sluggish blood circulation in the transplanted intestines and stomach, and the severed end of the esophagus. (3) Ill effects produced by traction and swallowing on the anastomosed part. (4) Low resistance of protein of the esophageal mucous membrane to pepsin and trypsin digestion^{21) 10) 12) 15)}.

In antethoracic esophago-gastrostomy and esophago-enterostomy necrosis with a relatively distinct boundary is apt to develop at the tip of the mobilized gastric

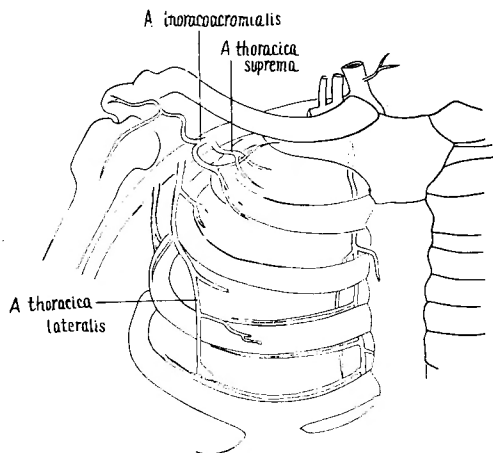
tube or jejunal loop thereby causing sutural insufficiency at the anastomosed part. And so it is considered that disturbance of the blood circulation in the isolated and antethoracically transplanted gastric tube or jejunal loop is mainly responsible for sutural insufficiency. Besides severance of the blood vessels involved in the process of isolation, traction, compression, and bending of the nutrient vessels, spasm of the vessels themselves, postoperative gradual development of tissue edema, and formation of thrombi seem play an important role in obstructing smooth circulation of the blood. M. TSUKUDA⁴⁹⁾ experimentally ascertained that the volume of circulating blood in the gastric tube and the jejunal loop was reduced immediately after the operative procedure to about 1/2 of the normal, and that this reduction was further intensified 24 hours later. Many remedies have been tried against this disturbance of blood circulation: ARAKI and ISHIHARA's covering with omentum majus of the transplanted gastric tube and jejunal loop⁶⁾; KATSURA et al.'s production of a jejunal segment with vascular supply and partial excision of its segment^{23/24)}; LONGMIRE and RAVITCH's intestinal-skin tube²⁹⁾; LONGMIRE's secondary esophago-gastrostomy²⁷⁾; LONGMIRE's anastomosis of A. et V. intestinalis with A. et V. thoracica interna²⁸⁾; SHUMACKER et al.'s stage division of mesenterial vessels¹¹⁾; EMERSON's gastric isolation combined with splenectomy¹⁰⁾; and a reversed gastric tube created from greater curvature of the stomach, combined with splenectomy (HEIMLICH)¹⁸⁾.

According to LONGMIRE and RAVITCH's method of preparing the intestinal-skin tube²⁹⁾, the jejunal loop with nutrient blood vessels is transplanted into the subcutis, and then covered with a skin tube. When new blood vessels from the skin have achieved sufficient vascularization in the loop, the nutrient vessels are cut. This pedunculated intestinal-skin tube is then gradually transferred upward till it comes between the antethoracically transplanted stomach and the cervical esophagus. LONGMIRE and RAVITCH say that it takes 3-4 months to transfer this skin tube to the upper thoracic or cervical region.

The present author experimentally studied the method of esophageal reconstruction by means of transplantation of the jejunal loop into the pectoral muscle; his intention was to lengthen the transplantation distance, utilizing new blood vessels coming into the loop from the muscle.

As shown in Fig. 28, M. pectoralis major et minor of man is nourished by the branches of A. axillaris, namely, A. thoracica suprema, A. thoracoacromialis and A. thoracica lateralis. These arteries run from the axillary region toward the median line, and consequently, even if the pectoral muscle is separated from its

Fig. 28.



attachment to the sternum and clavicle, it experiences no lack of blood supply.

The present author's method will be described as follows. A jejunal loop prepared after the method of WULLSTEIN is transplanted into *M. pectoralis major*, and when new blood vessels coming from the muscle have

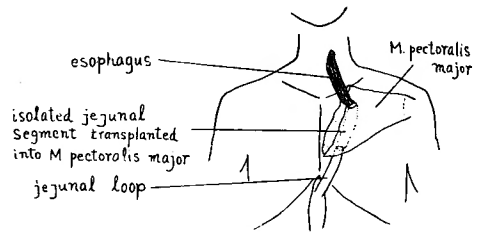
well developed in the loop, the muscle is cut from its attachment to the sternum and clavicle, and rotated along the chest wall toward the cranial side with its axillary region as an axis. To facilitate the transfer upward, one or two more *Aa. et Vv. jejunales* are cut asunder. This mobilized jejunal loop can be anastomosed with a higher portion of the esophagus. It also seems possible to sever the jejunal loop transplanted into the pectoral muscle together with the nutrient vessels, and rotate it toward the cranial side with *M. pectoralis major*, as described above, to anastomose it with esophagus, or with a separately produced gastric tube or jejunal loop (Fig. 29). This possibility has been experimentally investigated by the present author.

As *M. pectoralis major* is poorly developed in the dog, and cannot be used as a site of transplantation, *M. pectoralis minor* was used instead. The distribution of blood vessels being nearly the same as in man, this muscle is nourished by *Ramus profundus*, a branch of *A. mammaria externa*.

The formation of granulation tissue around the transplanted loop was histologically demonstrated one week after transplantation, and it was ascertained that blood was already running through newly-formed capillaries from the surrounding tissues into the loop. As time went on, these capillaries were further developed, and at the same time granulation gradually changed into connective tissue, thereby making adhesion between the loop and the surrounding tissue stronger. Next, the volume of blood stream running through the newly-formed capillaries into the loop was quantitatively determined, using a P^{32} -labeled erythrocyte suspension. As methods of quantitative determination of circulating blood in organs and tissues there are the following. (1) Injection of dyestuffs²⁰⁾⁽³⁸⁾⁽⁴⁷⁾. (2) Injection of contrast media³⁰⁾. (3) Injection of synthetic resin³³⁾. (4) Injection of mercuric chloride solution²⁶⁾⁽³⁹⁾. (5) Vital staining⁵⁶⁾. (6) Observation of blood vessel filling with a microscope²³⁾. (7) Measurement of outflowing blood volume⁵⁶⁾. (8) Inference of blood volume from organ temperature¹⁷⁾⁽⁵⁰⁾. (9) Vital experiments⁷⁾⁽¹⁹⁾.

All these methods, however, have some defect or other: one of them deals with an unphysiological condition; another is unfit for exact quantitative measurement; a third is susceptible to the influences of external factors, and so on. In the present investigation HEVESY's¹⁴⁾ P^{32} -labeled erythrocyte suspension was used. This method is now widely used, as it has the advantage of permitting a rather exact measurement in a physiological condition. However, due caution should be exercised

Fig. 29.



in using this method in case congestion or hemorrhage is present, for this method measures all the blood cells present, whether circulating or stationary. Such being the case, measurement by this method should be done only when blood circulation has become well-balanced and stable. It may be added, in passing, that M. MAJIMA³²⁾, one of the present author's associates, has already pointed out that the influences from the blood comprised in the heart, large blood vessels, and chest wall can be disregarded in the application of this method to measurement of blood volume in the intestines.

Experimental results were as follows. By vital measurement the volume of circulating blood in the loop was about 25% of the normal 10 days after transplantation, about 70% one month later, about 80% two months later, and three months later more than 70%, while by the incineration method it was 35.5% 10 days after transplantation, 74% one month later, 83.5% two months later, and three months later 80.2%. The above measurements showed that the volume of circulating blood in the loop rose suddenly one month after transplantation, reached the maximum in two months, and in the third month maintained this level, or rather decreased. This fact seems to have something to do with the progress of cicatrization in the connective tissue circumjacent to the loop. In the region near the abdominal cavity, adhesion of the loop to the omentum majus was noted, and high radioactivity was demonstrated there by incineration method. This may be considered to prove the effectiveness of covering with omentum majus of the transplanted gastric tube or jejunal loop.

MITSUO TSUKUDA⁴⁹⁾ also measured, using the same methods, the volume of circulating blood in the newly-formed blood vessels in the antethoracically and subcuta-

Fig. 30. Comparison of the volume of circulating blood between intramuscular transplantation and subcutaneous transplantation of jejunal loop by newly-formed blood vessels.

1. Measurement on living dog.
 - peripheral portion intramuscular
 - central portion } transplantation
 - peripheral portion } subcutaneous
 - central portion } transplantation
- (M. TSUKUDA)

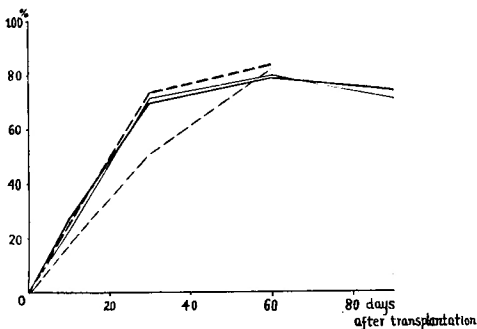
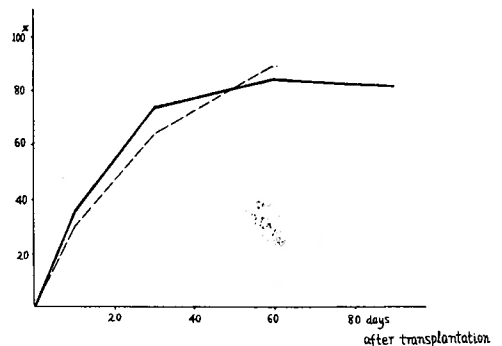


Fig. 31. Comparison of the volume of circulating blood between intramuscular transplantation and subcutaneous transplantation of jejunal loop by newly-formed blood vessels.

2. Measurement by dry incineration.
 - intramuscular transplantation (average)
 - subcutaneous transplantation (average)



neously transplanted gastric tube and jejunal loop. His experimental results are compared with the present author's in Fig. 30 and 31. Whether transplantation into the antethoracic subcutis or the pectoral muscle had been employed, any difference was hardly noted in blood volume of the transplantants through the newly-formed capillaries. But if compared at all, the volume was, if anything, a little larger in intramuscular transplantation in the early period after transplantation, but the rate of increase was slower.

Many studies have been prosecuted on the relationship between blood circulation and movement of the intestines. MACHIDA and YAMAMOTO noted¹⁹⁾, experimenting with the small intestines of the rabbit, that the intestinal movement was temporarily accelerated when blood circulation was blocked, but afterward slowed down; and that with restoration of blood circulation the intestines returned to normal movement after showing temporary acceleration. ICHIKAWA¹⁹⁾ noted in dogs that constriction of A. et V. mesenterica superior produced temporary changes in intestinal movement, but that these changes disappeared one week later. In the present investigation jejunal movement was markedly disturbed after transplantation, and though it was improved a little two or three months later, it still showed a prominent decline in motor function, if compared with the normal. Considering that the blood volume of the transplanted jejunal loop through the newly-formed vessels alone amounted to about 70-80% of the normal two or three months after transplantation, more prompt recovery of the motor function might seem more reasonable. This decline in motor function may be partly attributable to organic changes such as mild proliferation of interstitial tissue noted in the muscle layer of the jejunum in some cases. In cases where the loop was completely isolated (Section VI, Chapter I), such organic changes were not observed in the muscle layer, and so it is too early to explain slow recovery of the motor function by organic changes alone.

MORI³⁴⁾, after conducting total gastrectomy, recorded in curves the internal tension of the efferent part of the jejunum which now lay between the esophagus and the duodenum, and noted that this curve of internal tension came to resemble that of the stomach several months after operation. He regarded this phenomenon as an example of adaptation to a new surrounding. The jejunal loop transplanted into the pectoral muscle may also be considered to have a possibility of adapting itself to the passage of food. After all, this loop is capable of feeble, if not active, movement, and in this, has an advantage over the skin tube. As esophageal reconstruction necessitates vagotomy, its effects must also be taken into account. But, according to MORI, decline in motor function due to vagotomy disappears 30-34 days after operation.

Intense adhesion favors brisk vascularization in the transplanted loop, and augmentation of the circulating blood volume therein. In decortication of the transplanted loop from the pectoral muscle it was noted that its adhesion to the mesenteric border was very strong, but that to the opposite side was so weak as to be freed easily. In order to produce adhesion all around the loop, it is necessary either to cause aseptic inflammation in the serous membranc, or to excoriate the same. In

the present experiment, asbestos powder was sprinkled all around the loop, and it was ascertained that this procedure hastened vascularization. In cases treated with sprinkling of asbestos powder, blood volume in the loop 15 days after transplantation was the same as that in non-treated cases one month later, and the volume in the former one month later was the same as that in the latter two months later. That is, the asbestos-treated needed only about half the time to acquire the same blood volume coming through the new blood vessels. But in the 2nd month after transplantation the blood volume was nearly the same for both these kinds of cases, and vascularization seemed to have, by then, reached its limit. Two of the asbestos-treated cases contracted a serious infection around the loop, and developed abscesses. Asbestos-sprinkling is a very effective method, it is true, but in using it, due precaution must be taken against infection.

KATSURA²³⁾²⁴⁾, experimenting with a jejunal segment with blood supply, demonstrated by the determination of bleeding amount, and microscopical examination of mesenterial capillaries that excision of an unnecessary portion of the jejunum on the basal portion produced a good effect on the blood supply to the residual segment. The present author used a P³²-labeled erythrocyte suspension in vital experiments, and established the following fact: Diminution of vascular bed does not appreciably augment blood supply to the portion left unexcised in the jejunum with normal or nearly normal volume of circulating blood, while in the jejunum with the reduced blood stream the same procedure is effective to a considerable extent.

Taking into consideration the above experimental results, a jejunal loop was intramuscularly transplanted, and two months after transplantation it was made a completely isolated jejunal segment, and its anastomosis with the jejunum was successfully achieved. By this method, the period between transplantation of the loop and carrying-out of anastomosis extends over two months, awaiting the development of new blood vessels from the muscle. And even if asbestos is used, it only shortens the period by half a month. Accordingly, it is chiefly in cases of benign stricture of esophagus that this method is suitable for esophageal reconstruction.

In comparison with dogs, man has well-developed *M. pectoralis major*, and the possibility of successful esophageal reconstruction by this method is much greater for man.

Comparison between Antethoracic and Intrathoracic Transplantation

There are two methods of esophageal reconstruction, namely, antethoracic and intrathoracic. The advantages of antethoracic reconstruction are that by this method fatal occurrence of mediastinitis and pyothorax can be averted in the case of sutural insufficiency; and that the stomach recovers its secretory function more satisfactorily than by the other method in the case of esophago-gastrostomy. Iro²²⁾ conducted antethoracic subcutaneous, and intrathoracic esophago-gastrostomy respectively on 10 dogs, and noted that all the cases which underwent the former procedure developed sutural insufficiency, while suture was perfect in 7 of those subjected to the latter. This difference in operative results between the two methods is very

striking, but clinical cases of intrathoracic anastomosis often develop sutural insufficiency, and if once this occurs, it nearly always proves fatal. Therefore, choice between the two methods is not so simple an affair; it needs careful consideration.

The antethoracically and the intrathoracically transplanted loops receive different external influences: the presence of negative pressure in the thorax; difference of intrathoracic temperature from that of antethoracic subcutis; mechanical compression, bending, and traction of the nutrient blood vessels, different neighboring organs (especially the presence of the pleura). In the present investigation two of them, namely, negative pressure and temperature difference, were taken up for study.

Effects of Negative Pressure on The Transplanted Loop

An intrathoracically-transplanted organ necessarily sustains the influences of intrathoracic negative pressure. This negative pressure may well be considered to quicken inflow of arterial blood, and impede outflow of the venous, thereby causing stagnation of blood. In the present investigation I tried to estimate the effects of negative pressure with use of an oxygraph or P^{12} -labeled erythrocyte suspension, but found that its effects on blood circulation in the transplanted loop were quite negligible.

Temperature in The Transplanted Loop

It was ascertained that the temperature of the loop transplanted into the antethoracic subcutis was commonly lower than that of the intrathoracically transplanted by 0.3° - 3.0° C. This temperature difference between the two is quite reasonable, for one loop was in the thorax, while the other was near the skin where loss of heat constantly takes place. Even if the loops were transplanted ante- or intrathoracically, the temperature difference at the necrosed tip portions was almost the same as that of the root portions. From this fact it may be inferred that temperature of the loop has no relationship with occurrence of necrosis.

The experiments described in Section III, Chapter II, were done to ascertain the minimum condition for resistance against necrosis. In both kinds of transplantation portions of the transplanted loop with blood volumes, less than 55% of the normal always fell into necrosis, and difference in method of transplantation had nothing to do with development of necrosis. It is considered that the possibility of development of necrosis is nearly the same for both methods, so long as the same volume of circulating blood is maintained. Any marked difference in operative results between the two methods may, therefore, be attributable either to such mechanical factors as compression and bending of the nutrient vessels due to length of transplantation distance, or to the presence or not of defensive action of the pleura etc.

SUMMARY

Experimental investigation were carried out on esophageal reconstruction by means of transplantation of a jejunal loop into the pectoral muscle. This method aims at the utilization of postoperative vascularization in the transplanted loop. Dogs were used as experimental animals. Conclusions reached are given below.

(1) After injection of India ink, development of new blood vessels from the surrounding tissues into the transplanted loop was histologically examined, and it was ascertained that one week after transplantation blood was already streaming into the loop through the new blood vessels in the granulation tissue which had formed around the loop. Mild atrophy was noted in the loop tissue, but later it tended gradually to disappear.

(2) A P^{32} -labeled erythrocyte suspension was used quantitatively to determine the volume of blood going through the newly-formed blood vessels into the loop. It was made evident this volume was about 20-30% of the normal 10 days after transplantation, and two months later reached 80%. It was also proved that vascularization was quickened by sprinkling of asbestos powder on the tissues circumjacent to the loop.

(3) The transplanted loop showed a conspicuous decline in motor function. Though this function was improved a little two months after transplantation, it was still seriously disturbed, compared with the normal.

(4) The jejunal loop was transplanted into the abdominal muscles, and two months later it was made a completely isolated jejunal segment, its blood supply being cut off. Its anastomosis with the jejunum was successfully accomplished. Further, the loop was transplanted into the pectoral muscle, and after development of new vascularization, mesenterial blood vessels were severed. The possibility of widening the extent of antethoracic jejunal transplantation was thus experimentally established.

(5) Comparison was instituted between antethoracic subcutaneous and intra-thoracic transplantation. The effects of negative pressure and temperature difference of the transplanted regions were also experimentally investigated. It was also clarified that the occurrence and extent of necrosis rather depended on the volume of circulating blood in the transplanted segments than on the methods of transplantation.

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(和 文 抄 録)

胸郭前食道再建術に関する実験的研究

とくに移植空腸の血行動態と胸筋内移植空腸の利用について

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食道再建術でもつとも重要な問題は吻合部の縫合不全であるが、その発生の主要原因が移植胃・腸管における血行障害であることは既に教室先人が実験的にこれを立証した。そこで自分はその対策の一つとして、残余食道と腸管とを縫合させることを企てたが、この際いかにして血流のよい移植腸をうるかを実験に匡したのが本研究である。胸筋の栄養血管は主に腋窩部から流入するが、まず空腸管を胸筋内に移植して、一定期間放置し、筋から腸管に対して血管が新生されるものか否かを検し、そしてその後においてのかゝる筋肉内移植腸管の利用可能性について検討した。

その為に成熟雄犬を用いて以下の実験を行った。

1) Wullstein 法に準じて空腸管を作製し、左小胸筋を外側縁から正中側に向つて深淺2層に分けたものの間に移植し、移植後の各時期における血管新生状態を組織学的に検討した。即ち、移植腸管の本来の連続を断つて、新生血管だけで栄養される状態として、大動脈から墨汁液を注入すると、移植後1週間ですでに新生血管を通じて移植空腸管内への血流のあることが確められた。また、移植空腸組織には一時軽度の萎縮像がみられたが、後には次第に回復した。

2) 次に、胸筋内移植空腸への血行量を P^{32} 標識赤血球を用いて測定すると、新生血管だけを通じて移植片に達する血行量は、移植後10日で正常空腸のその20~30%、1ヵ月後には70~75%、2ヵ月後には約80%に達した。この際アスベスト粉末を移植空腸周囲に散布すると、血管新生が促進されて、半ヵ月で正常空腸の65~70%、1ヵ月で約80%に達することを認めた。

3) 先に教室間嶋の立証した、空腸管は正常部の70%以上の血行量を保てば壊死に陥らないという事実と、以上の実験結果からすれば、移植後2ヵ月すれば、新生血管だけで筋内移植空腸が栄養されうる状態

になるものと考えられた。そこで更に次の実験を行ったのである。空腸管を腹直筋と腹横筋の間に移植して、2ヵ月後に新生血管だけで栄養される遊離空腸片を作成し、これを正常空腸に吻合したが、これは美事に成功した。そして胸筋内移植空腸を、その胸筋の胸骨附着縁を切断し胸筋と共に移動させて、移植空腸の挙上範囲を胸骨上端まで増大させようことを実証した。

4) またかゝる胸筋内移植空腸の運動機能を腸内圧曲線描記法によつて検討してみると、移植後に著しい機能低下のあることを認めた。

5) 臨床的には胸腔内食道一胃或いは一腸吻合術が胸郭前のそれに比べて縫合不全を起し難いというように考えられてもいるので、この問題について2, 3の検討を行った。

i) 即ち陰圧の影響をみるために、血管茎を有する空腸片を作製し、平圧時と、自家考案の装置によつて7~8 cmH₂Oの陰圧を律動的に負荷せしめた時の兩者について、漿膜下酸素分圧をOxygraphiによつて、また血管茎の血行量を P^{32} 標識赤血球によつて測定したが、陰圧負荷による影響的变化は認められなかつた。

ii) 更に胸郭前皮下と胸腔内に移植した空腸管の温度を測定すると、後者が一般に高値(約3°C)を示したが、腸管自身の温度は壊死に直接関係しないことを証明した。

iii) 次に約30cm長の空腸管を作り、 P^{32} 標識赤血球を用いて各部位の血行量を測定した後、胸郭前皮下と胸腔内に移植して、後は壊死に陥つた部はいずれも正常部の55%以下の血行量を示した所であつて、両移植法において差異のないことを認めた。

iv) 従つて同一の血行量を有していれば胸郭前皮下或いは胸腔内いずれの移植法によつても壊死発生の可能性は同様であると云つてよい。



Fig. 3. One week after transplantation ($\times 180$)



Fig. 4. 3 weeks after transplantation ($\times 50$)

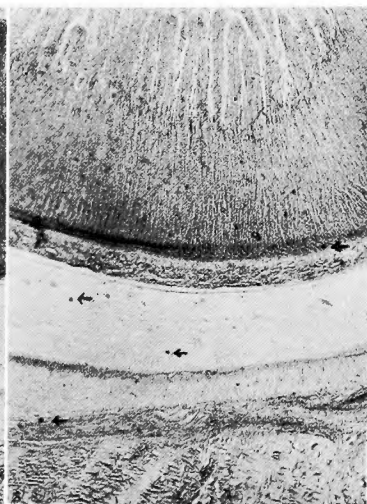


Fig. 5. 6 weeks after transplantation ($\times 50$)

Histological findings of jejunal loop transplanted into *M. pectoralis minor*. (Injection of India ink only through the newly-formed blood vessels.) \downarrow : India ink

Curves of internal tension of jejunal loop transplanted into *M. pectoralis minor*.

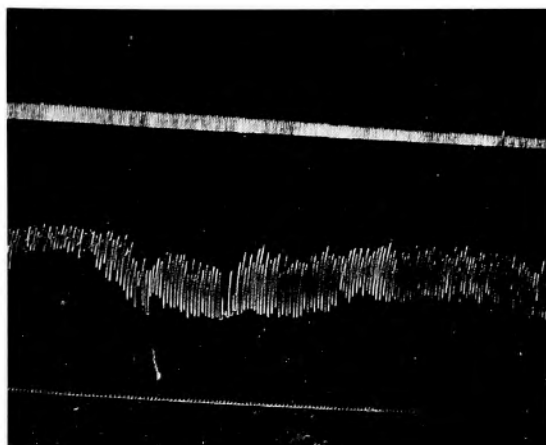


Fig. 8. Control (normal jejunum)

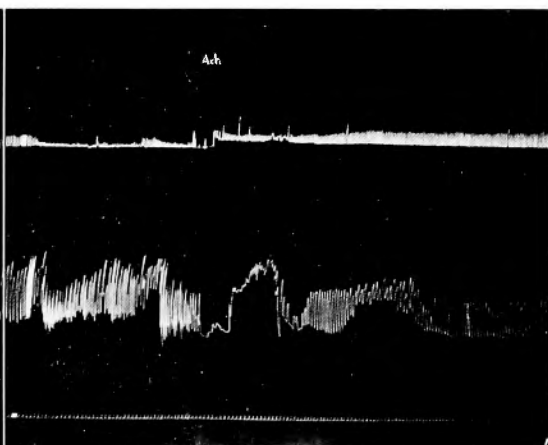


Fig. 9. Control (Administration of 2 mg/kg of acetylcholine)

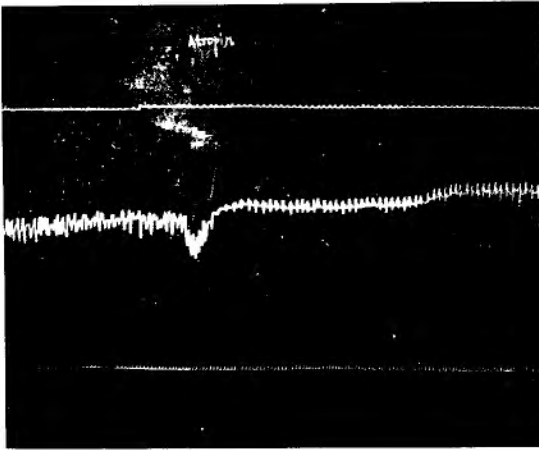


Fig. 10. Control (Administration of 0.01mg/kg of atropin)

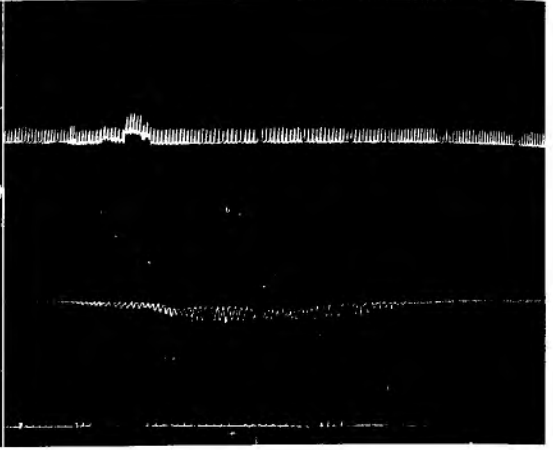


Fig. 11. 15 days after transplantation

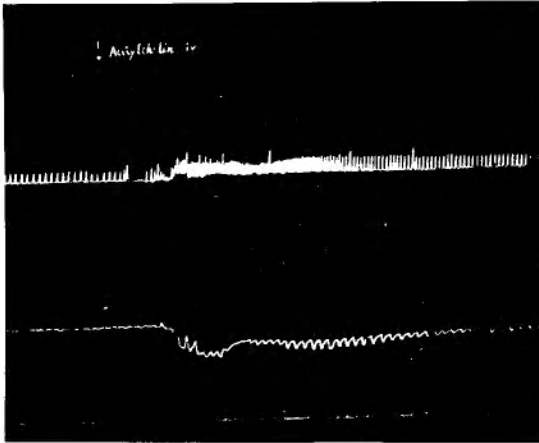


Fig. 12. 15 days after transplantation
(Administration of 2 mg/kg of acetylcholine)

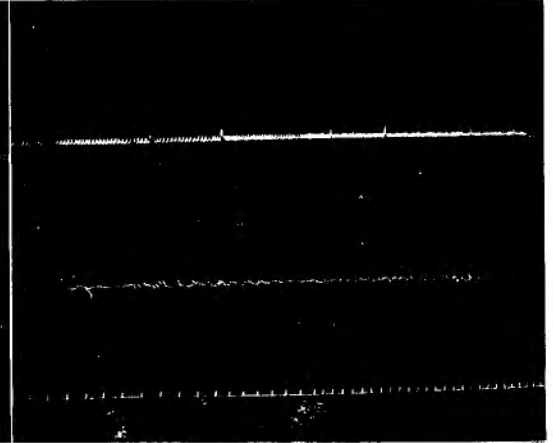


Fig. 13. 1 month after transplantation

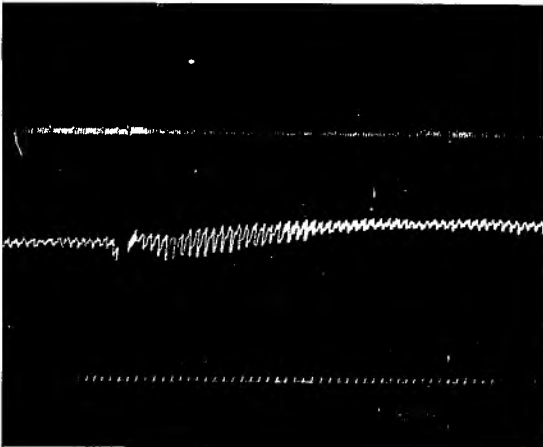
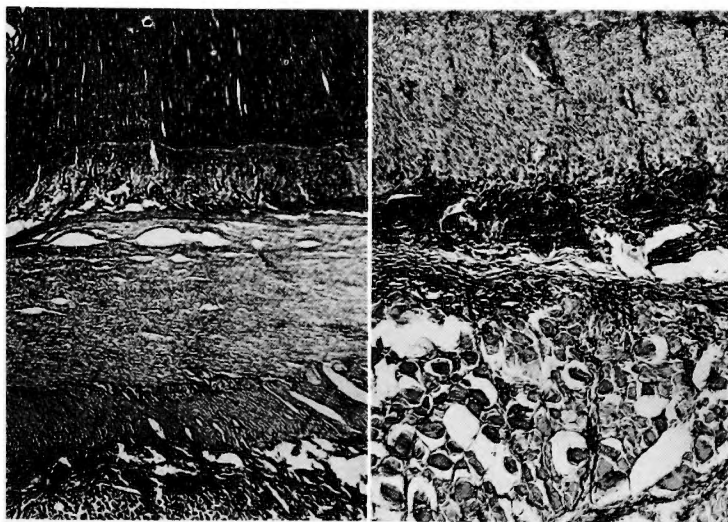
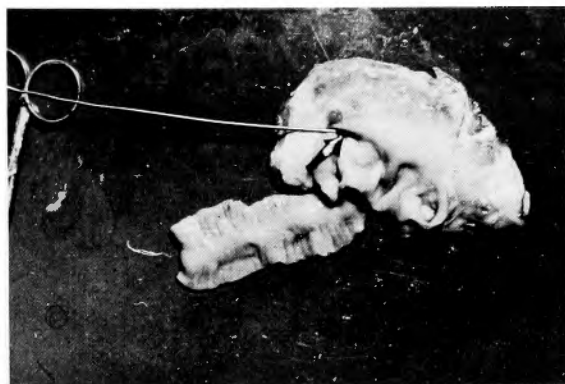
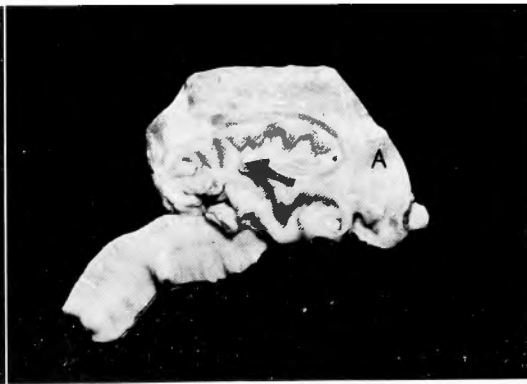


Fig. 14. 2 months after transplantation

**Fig. 17.** ($\times 60$)**Fig. 18.** ($\times 250$)

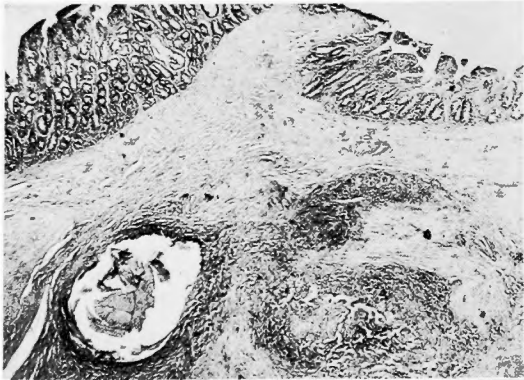
Histological findings of jejunal loop transplanted into *M. pectoralis minor* (with sprinkling of asbestos powder).
2 weeks after transplantation.

**Fig. 22.****Fig. 23.**

Experiment of anastomosis using isolated jejunal segment transplanted into the abdominal muscles with blood supply by newly-formed blood vessels alone.
(\downarrow : portion of anastomosis)

A: Abdominal muscle into which isolated jejunal segment was transplanted.

Histological findings of anastomosed region.



←**Fig. 24.** right side : isolated jejunal segment
left side : normal jejunum
(× 60)

Fig. 25. cell infiltration around the sutural thread (× 120)→

